

Cherenkov Flashes and Fluorescence Flares on Telescopes: New lights on UHECR Spectroscopy while unveiling Neutrinos Astronomy

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Abstract

Multi-GeV and TeVs gamma sources are currently observed by their Cherenkov flashes on Telescopes (as Magic, Hess and Veritas), looking vertically up into sky. These detectors while pointing horizontally should reveal also the fluorescence flare tails of nearby down-going airshowers. Such airshowers, born at higher (tens km) altitudes, are growing and extending up to lowest atmospheres (EeVs) or up to higher (few km) quotas (PeVs). These fluorescence signals extend the Cherenkov telescopes to a much higher Cosmic Ray Spectroscopy. Viceversa, as it has been foreseen [9] and only recently observed, the opposite takes place. Fluorescence Telescopes made for UHECR detection (as AUGER ones) may be blazed by inclined Cherenkov lights: less energetic, but frequent (PeVs) CR are expected to be often detected. Nearly dozens blazing Cherenkov at EeV should be already found each year in AUGER, possibly in hybrid mode (FD-SD, Fluorescence and/or Surface Detector). Many more CR events (tens or hundred of thousands) at PeVs energies should be blaze Cherenkov lights each year on the AUGER Fluorescence Telescopes. Their UV filter may partially hide their signals and they cannot, unfortunately, be seen yet in any hybrid mode. At these comparable energy the rarest UHE resonant antineutrino $\bar{\nu}_e + e$ interactions in air at $\frac{M_W^2}{2m_e} = 6.3$ PeV energy, offer enhanced W^- Neutrino Astronomy showering at air horizon, at $\sim 90^\circ$, while crossing deep atmosphere column depth or Earth (Ande) boundaries. However, AUGER FD are facing opposite way. An additional decay channel rises also (after resonant neutrino skimming Earth) via their secondary τ exit in air, by decay in flight via amplified showering: $\bar{\nu}_e + e \rightarrow W^- \rightarrow \bar{\nu}_\tau + \tau$. Moreover, expected horizontal UHE GZK neutrinos $\nu_\tau \bar{\nu}_\tau$ at EeVs energy, powered by guaranteed cosmogenic GZK [11,15], $\nu_\mu \bar{\nu}_\mu$ flavor conversions (in cosmic distances), are also producing penetrating UHE EeV lepton taus that could sample, better and deeper than PeVs ones, the Earth skin. Such almost horizontal and up going tau showers, originated by UHE astronomical neutrino, may shower and flash by Fluorescence and/or Cherenkov diffused lights at Auger Sky in a few years (nearly three). Viceversa, at Hess, MAGIC and VERITAS Horizons, at tens or a hundred kilometer distances, the same up going $\tau \bar{\tau}$ airshowers might rise via fluorescence. On axis they might blaze (rarely) as a Cherenkov flashes below the horizons, possibly correlated to BL Lac or GRB activity. Also UHE (1 – 0.1 EeV) GZK τ showering, can be observed upward once reflected onto clouds. The geomagnetic splitting may tag the energy as well as the inclined shower footprint as seen in a recent peculiar event in AUGER. Additional stereoscopic detection may define the event origination distance and its consequent primary composition, extending our understanding on UHECR composition.

Key words: Cosmic Rays, Cherenkov, Fluorescence, Neutrino, AUGER, Extensive Air Showers

PACS: 96.50.S-, 96.50.sb, 96.50.sd, 98.70.Sa

1. Introduction

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Cosmic Rays is a mature, century old Science. It still hides its secrets beyond the amazing ho-

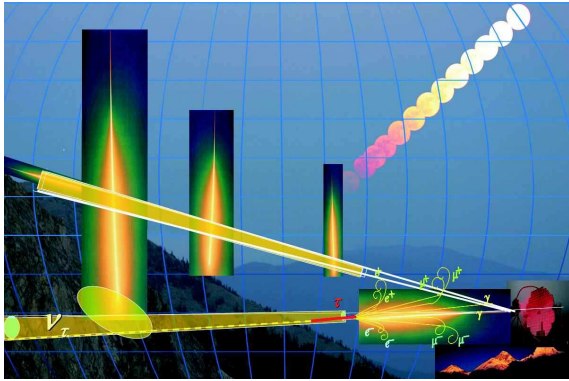


Fig. 1. The different geometry for a Magic-like telescope searching at horizon airshower tails. Nearby PeVs CR can be observed by fluorescence at few km altitude while a more powerful airshower (EeV), might be observed at lower altitudes because of the larger slant depth on far edges. Cherenkov airshowers might blaze in the telescope if in axis. Rarest up-going Tau airshower may escape the Earth at far horizon, leading to up-going flashes. Guaranteed nearby CR (PeVs-EeVs) airshower Cherenkov lights, may also be observed by reflection from nearby hills or mountains (as in Magic or Veritas), or from the sea [6]

mogeneity and isotropy in all energy range. Only photons, our best neutral courier in Astronomy, offered up to now a view of the Universe from lowest (radio) to highest (TeV) energies. Because of the TeVs-PeVs-EeVs photon self-interaction with relic IR (Infrared), CBBR (Cosmic Black Body Radiations) and Radio backgrounds, UHE (Ultra High Energy) photons are bounded in nearby Universe. Therefore neutral neutrinos may offer a far insight of CR sources because of their weak interaction for we could also reveal the inner core of their mysterious accelerators. After a decade, the exciting hopes of a discover by AGASA and by Hires of (an almost undeflected) UHECR traces, a long waited new Particle Astronomy have been frustrated by AUGER results. No UHECR clusterings toward BL Lacs or AGN seems to arise up now. Even if GZK cut-off (the CBBR opacity to nucleons above few 10^{19} eV flux [11,15]) appeared to be finally confirmed by Hires [12] and AUGER [17]: no Galactic or nearby Universe map within GZK cut off volume seems to be correlated with these UHECR events. If homogeneity and isotropy will survive AUGER, Z-Burst model [5], linking far cosmic UHE ZeV ν sources scattering on $\bar{\nu}$ relic ones, remains the unique natural option. Otherwise, our Near Universe as Virgo and our Super- Galactic group and/or plane, must rise soon. Moreover an unexpected heavy composition of extreme UHECR makes more urgent an in-

dependent UHECR spectroscopy. As well as the discover of UHE $\nu\bar{\nu}$ GZK, rare but guaranteed GZK [11,15] secondary neutrino traces. To this project and to its solution we address in present paper.

1.1. Fluorescence flares within Cherenkov Telescope

We foresee that Cherenkov telescopes while pointing at horizons ($\geq 80^\circ$ zenith angles) may observe a truncate image (a cylinder like) of downward fluorescence airshower, lightening (See Fig.1). These flaring views may appear often at few tens km distance, toward 80° angle for tens PeVs (or a hundred km at $\simeq 85^\circ$ for EeVs energies), as often as once a night. Nearby hills or reflecting sea may disturb the detection. We foresee that such a discover must occur soon, amplifying MAGIC, VERITAS and HESS high energy CR yields.

1.2. Cherenkov blazing photons on Fluorescence Telescopes

The opposite also take place: Cherenkov photons may hit Fluorescence Telescopes, even if most Fluorescence detectors are masked by UV filter. Indeed the blazing Cherenkov lights are collimated into a narrow cone; therefore they are more rarer than Fluorescence isotropic signals. We may estimate that few hundreds of EeV airshowers in a year might hit with Cherenkov the AUGER FD. Probably only a few dozens are well revealed with the FD and by muons on SD, as well as Cherenkov lights, as it has been foreseen [9]. A very peculiar and pedagogical event has been shared on line by AUGER collaboration [2]. We shall analyze that event in the next sections.

2. Splitting and bending of UHECR at horizons

The bending of geomagnetic field plays a key role in inclined airshowers. In usual *vertical* airshowers, the final result is a conical three-like shape, because the electron pairs avalanche is spread by random walk in Coulomb scattering at final sea level altitude. On the contrary, inclined airshower develop at high quota at low air density, where the Coulomb scattering is negligible. The Lorentz force may separate better the electron pairs (mostly at GeV energy) into a twin arc jet-like tails. The same bending takes place for muons on the ground (recorded

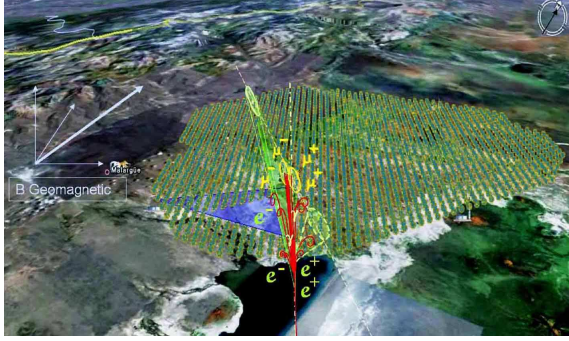


Fig. 2. The rare inclined UHECR event seen in axis from above. To this picture derived by an AUGER presentation, we overlapped a drawing of the airshower components, their bending and the consequent geomagnetic \vec{B}_\oplus splitting. Note the \vec{B}_\oplus vector pointing to North and upward respect the ground. Note also the consequent vertical and lateral charge bundle separations. Each charge-bundle follow its bend trajectory that generate its own Cherenkov beam. The comparability between $\vec{B}_{\oplus\perp}$ and $\vec{B}_{\oplus\parallel}$ field vector modules, is the cause of a similar angular (lateral-vertical) deflection. Their projection on the ground is not symmetric at all. The dashed-ellipse on the right side marks our forecast Cherenkov spot made by e^+ split shower component, undetected (out of a Cherenkov reflection on the ground hardly recorded) by Los Leones FD station which instead detected the main Fluorescence flare. The top-left side ellipse, marks the probable Cherenkov spot born by negative electrons blazing on Coihueco telescope.

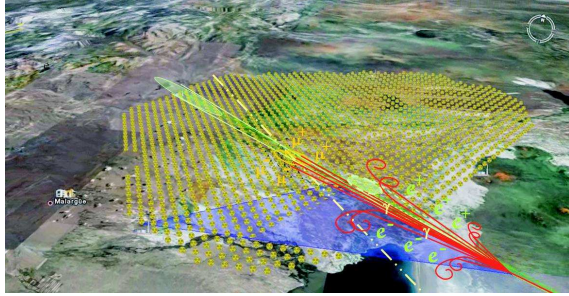


Fig. 3. The same Auger event seen from another angulation [2]. The inclined UHECR is reaching the ground on the center, where the muon pairs are clustering into a twin overlapped ellipses. The arrival angle is approximated at 80° zenith angle [2]. Our consequent estimated primary energy is above few EeV (possibly around ten EeV). The Cherenkov blaze time on Coihueco τ' , being slightly off axis ($\sim 5^\circ$), must appear much shorter (one or two order of magnitude) than the Fluorescence duration signal $\simeq \tau$ reaching Los Leones, because of both the geometric and the relativistic shrinkage, $\tau' = \tau_o \cdot (1 - \beta \cos(\theta))$. The FD, because of lack of angular resolution in Auger Telescope, might be unable to reveal the electron pair splitting. The Cherenkov bending angle extends a few degrees: at Coihueco the airshower beam is roughly at 5° above horizons, while its shower beginning reaches $7^\circ - 9^\circ$ angle. Therefore the Cherenkov splitting shape might be marginally detectable by Coihueco Telescope, by a two-three pixels separation along its inclined polarized axis.

by SD). However, because of large inclined distances and because of muon decay in flight, not to mention their larger slant depth, the surviving muon bundles reach the Earth at higher energy ($\simeq 20$ GeV at 80°) than electron ones. The muon Lorentz radius is consequently much larger (nearly 20 times at 80°) than electron ones. Therefore inclined muons suffer less bending than e^\pm pairs bent in earlier showering stages, than the muon lobes often overlaps as in Fig.2. Moreover, the geomagnetic B_\oplus field is not (usually) just parallel (B_\parallel) to the Earth, but it shares an escaping (or ingoing the Earth) vertical component, B_\perp . In particular at South Pole (close to the AUGER location), or eventually in the North one, B_\perp is comparable to B_\parallel . In conclusion the B_\parallel field splits a downward inclined (horizontal) event, respectively into a twin upper-down component while B_\perp field opens the twin showers into right-left direction. Both effects usually occurs, defining a correlated polarized axis. This footprint offers a powerfull tool in airshower diagnostic. We foresaw and discussed such a splitting role for Auger in past papers [9].

3. Inclined Auger Cherenkov-Fluorescence event

The inclined airshowers experience deep air column depth that filter their survival probability and intensity at each zenith angle. Such a tuned filter suppresses the lowest energy showers but leads to a complex footprint for the others. Indeed the larger the hadronic airshowers zenith angle is, the higher their main showering (electron pairs) altitude must be. At highest quota, the air density is so low, $\rho = \rho_o e^{-\frac{h}{h_o}}$, that the pair energy threshold increases $E_{min} = 20 \text{ MeV} \cdot e^{\frac{h}{2h_o}}$. Consequently also the Cherenkov luminosity decreases $\frac{dN_{ph}}{dx} \simeq 25e^{-\frac{h}{h_o}} m^{-1}$, and the consequent Cherenkov airshower angle shrinkage: $\theta_{Ch.} = 1.4^\circ \cdot e^{-\frac{h}{2h_o}}$, where the air scale factor is $h_o = 7.25 \text{ km}$. We remind that fluorescence yield is almost stable up to 20 km altitude and at higher altitudes it decays linearly with height. The geomagnetic field, unable to deflect the UHECR primary, may well deflect its low energy secondaries (mostly e^\pm and only partially their higher energy muons μ^\pm). The most inclined the airshower (85° or above) must rise their main showering lights (Fluorescence or Cherenkov) at highest altitudes ($\simeq 20 - 30 \text{ km}$). Because of the present Auger solid angle view, extending up to 30° from horizon, such

an inclined horizontal shower must be located very far (≥ 40 km) edges from the telescopes. At those distances only highest event might be rarely observed by Fluorescence lights, but not by Surface Array. And viceversa: extreme inclined events seen by Cherenkov tanks cannot be observed (because geometry) by FD. At lower altitudes *only neutrino may shine horizontally* as discussed below. One of us predicted the inclined Cherenkov-Fluorescence event in earlier papers [9]. Such a rare inclined pedagogical event (see figure captions Fig.2 and Fig.3) summarize the splitting in FD-Cherenkov lights: a high energy airshower has been detected by FD in Los Leones while being observed by Coihueco Fluorescence Telescope, via the shower Cherenkov light. The blaze rise from highest altitudes and its main axis reaches the ground at the Auger array center where muon bundles hit the tanks. Being muons at ~ 20 GeV, they are less bent than the electron pairs in main shower. The electron components shine in Cherenkov mode, quite inclined as described in Fig.2 and Fig.3 toward Coihueco and elsewhere in the array as shown by dashed ellipse; The exact calibration of the airshower earlier interaction defines the primary crosssection as well the consequent primary nature: the higher altitude for heavier nuclei, the lower quota for a nucleon.

4. Unveiling GZK Neutrino Showering

To estimate a minimal GZK neutrino flux [11,15] we note that the Auger UHECR at GZK knee $E = 3.98 \cdot 10^{19} \text{ eV}$ is corresponding to a small fluency ($\Phi_{\text{GZK}} \simeq 6.6 \text{ eV} \cdot \text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$); this value for sake of simplicity may hint an underlying neutrino GZK flux as large as ($\Phi_{\text{GZK}\nu} \simeq 10 \text{ eV} \cdot \text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$) for each flavor state: $\Phi_{\nu_\tau + \bar{\nu}_\tau} \simeq 20 \text{ eV} \cdot \text{cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ for up-going GZK taus [8,10]. This value should be not too far from the real one. For simplicity we assumed around EeV energy a minimal flat ($\propto E^{-2}$) neutrino τ spectra (the sum of both two species), comparable with the WB one, at a constant fluency. Our results (differential and integral flux) for Auger are summarized in Fig. 4,5. It is evident that at EeV in rock matter (as the one in Auger territory), the expected rate reach one event in three years. An enhancement, made by peculiar Ande screen, may amplify the rate from the West side (at least doubling this expected rate).

One signature of young Neutrino airshower is its curvature and time structure: they may indicate the

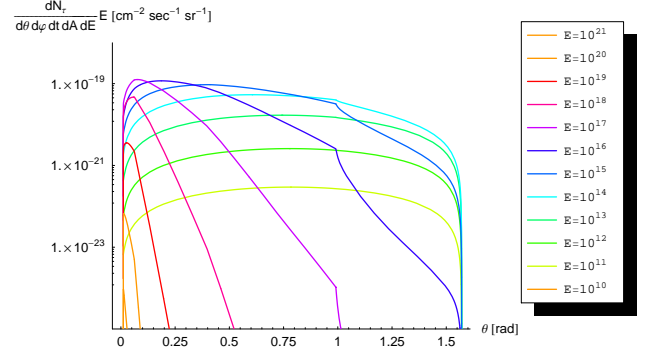


Fig. 4. Estimate of differential angular number flux of Tau airshowers at different energies due to an average (Fermi-like or Waxman-Bachall like) GZK neutrino fluency around EeV energy, for each flavor state, equal to $\Phi_\nu = 10 \text{ eV cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$. One may note the negligible absorption at $10^{10} - 10^{14}$ eV, the larger and larger opacity at higher energies toward vertical directions, the discontinuity at 57° due to inner terrestrial core density step, the surviving tau flux at horizon edges. [8,9]; For comparison see [16].

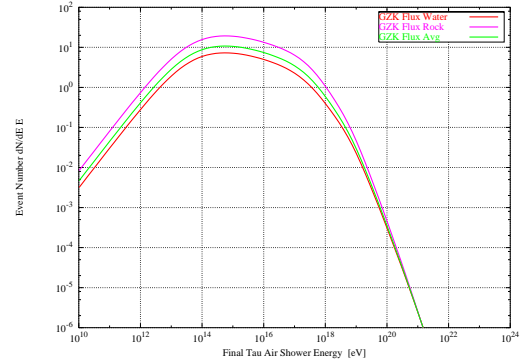


Fig. 5. Estimate angular integral event rate in three years at AUGER area as above. As it may note at EeV edges, on rock soil, where AUGER detection reaches the whole area, there must be an event in three years from now. The rate maybe increased by Cherenkov reflection lights on clouds at $0.1 - 1 \text{ EeV}$ energy range [10].

Tau neutrino origin [3]. However, it is not the unique and most powerful imprint. The Auger angular resolution and its limited statistics will not allow to reveal any Moon or Solar Shadows, at least in a decade. The Ande shadow [7,14] however is at least a thousand times larger than the moon one; however on the horizons the UHECR rate decreases drastically, nearly three order of magnitude; nevertheless the West-East asymmetry would rise around $\geq 88^\circ$ horizons at Coihueco and Los Leones, as a few hundred missing or asymmetric events, making mean-

ingful its detection in one year. It *must* be observed soon by tuned trigger and angular resolution care. Its discover would be an important crosscheck of the Auger experiment. Within this Ande shadow horizons, taus might be better born, at least one any three year, mostly in FD (Fluorescence Detector) but also in SD (Surface Detector). In this decade Auger may find up-going Tau in its whole area at the rate (see Fig.4) of $N_{10^{18}eV} = 1.07$ event each three years; at lower energy, $N_{3 \cdot 10^{17}eV} = 3$ the Auger area detection is reduced ($\simeq 0.33$), leading to an important event rate $N_{E\tau=3 \cdot 10^{17}eV} \simeq 1.1$. Because additional events are unconfined (Horizontal) airshower, this increases the detection mass and its discover rate, almost doubling (from the West) the expectation rate. Finally a possible discover of FD could be amplified by final flash via Cherenkov reflection on the clouds (see Fig.4 in [10]). Being cloudy nights a third or a fourth of the whole year, this time may be an occasion to exploit even if Moon arises. In partial disagreement to some earliest[1] and most recent Auger prospects [4] requiring one or two *decades* for a WB flux GZK neutrino discover, we foresee (in see also [10]) a sooner discover of GZK τ neutrino astronomy, possibly within two-three years from now. Auger may be even the first experiment in the world to detect a tau natural flavor regeneration processes. To reach and speed this goal we suggest to tune the electronic trigger of FD to horizontal airshowers, to map the UHECR Ande shadows, to insert more Cherenkov telescopes to the Ande line.

5. Conclusions

Cherenkov and Fluorescence Telescope may enlarge their view and role tracing both lights. The wider CR range will allow a better spectroscopy at PeV-EeV (knee-ankle) regions and a more detailed anatomy of UHECR composition. MAGIC, HESS and VERITAS may soon trace the Fluorescence lights of downward UHECR airshowers. MAGIC and VERITAS must reveal the Cherenkov reflections also on nearby Mountains. The recent inclined UHECR event in Auger [2] clearly foreseen in [9] discussed in this paper offer the first footprint for such rich information derived by muons bundles, electron pairs showering and splitting into polarized Cherenkov and Fluorescence traces. Within this novel spectroscopy a hidden Neutrino Astronomy wait to be finally unveiled [10].

References

- [1] Aramo C. et al. *Astropart. Phys.* 23 (2005) 65-77
- [2] A. Watson interview, www.phys.psu.edu
- [3] Bertou X. et al. 2002, *Astropart. Phys.*, 17, 183
- [4] Blanch B., Auger Coll., ICRC07, arXiv:0706.1658v1
- [5] Fargion D., Mele B., & Salis A., 1999, *ApJ* 517, 725; Fargion D., et al., 2003, *Recent Res. Devel. Astrophysics.*, 1, 395
- [6] Fargion D. et al., *Nuclear Physics B (Proc. Suppl.)* 165 (2007) 207, 214
- [7] Fargion D., 2002, *ApJ*, 570, 909; Fargion D. et al. 1999, 26th ICRC, HE6.1.10, 396-398
- [8] Fargion D., et al. 2004, *ApJ*, 613, 1285; Fargion D., et al. *Adv. in Space Res.*, 37 (2006) 2132-2138; Fargion D. et al., *Nuclear Physics B (Proc. Suppl.)* 2004, 136, 119
- [9] Fargion D. *Prog. Part. Nucl. Phys* 57, 2006, 384-393; Fargion D. et al. *Adv. Space Res.* 37 (2006) 2132-2138; Fargion D. astro-ph/0604430 Third NO-VE Int. Ed. M. Baldo Ceolin; Pag. 515- 538, (2006); D. Fargion. *Frascati Phys. Ser.* 42 (2006) 119-137
- [10] Fargion D. et al. arXiv:0708.3645v2;
- [11] Greisen K 1966 *Phys. Rev. Lett.* 16 748
- [12] The HIRES Collaboration, *Ap.J.* 636, 2006, 680-684
- [13] Medina Tanco G. for Auger Coll. arXiv0709.0772M
- [14] Miele G. et al. *Phys. Lett. B* 634 (2006) 137-142
- [15] Zatsepin, G.T, Kuz'min, V.A. *Zh. Eks. Teor. Fiz., Pis'ma Red.* 4 (1966) 144
- [16] Zas E. *New J. Phys.* 7 (2005) 130
- [17] T. Yamamoto, Pierre Auger Collaboration, 30th ICRC, arXiv:0707.2638, v3